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Research article

# An investigation of coastal vulnerability and internal consistency of local perceptions under climate change risk in the southwest part of Bangladesh

M.A. Rakib[a,c,*], Jun Sasaki[b], Sosimohan Pal[c], Md. Asif Newaz[d], Md. Bodrud-Doza[e], Mohammad A.H. Bhuiyan[e]

[a] Graduate Program in Sustainability Science - Global Leadership Initiative, Graduate School of Frontier Sciences, The University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa, Chiba, 277-8563, Japan
[b] Department of Socio-Cultural Environmental Studies, Graduate School of Frontier Sciences, The University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa, Chiba, 277-8563, Japan
[c] Department of Disaster Management, Begum Rokeya University, Rangpur, 5400, Bangladesh
[d] Environmental Science Discipline, Khulna University, Khulna, 9208, Bangladesh
[e] Department of Environmental Sciences, Jahangirnagar University, Savar, Dhaka, 1342, Bangladesh

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ABSTRACT

Climatic threats force disruption on community lifestyles by impairing social factors, the fundamental components of ensuring social sustainability. This study investigates the situational factors affecting the consequences on coastal livelihoods, and social activities; it also considers the effectiveness of traditional knowledge in reducing possible risks. Both qualitative and quantitative methods were employed, including questionnaire survey for identifying the local perception of climatic impacts alongside the impacts on daily activities. Interviews, field observations, and multivariate analyses were performed to explain the vulnerability status in coastal communities. Results show that most livelihood sectors were severely affected by the long-term and repeated actions of climatic hazards, such as cyclones, associated with a number of unavoidable risks making people susceptible to damages in social wellbeing. In addition, saltwater intrusion damages drinking water supply and crop farming, which can cause diseases among coastal communities, but very few attempts have been made to provide alternative sources of drinking water at a household level. Moreover, principal component analysis (PCA) and cluster analysis (CA) revealed significant interfaces between local perceptions and the socio-and agro-environmental factors changing the overall status of regional hazards. Thus, the situation exhibits coastal hazards, social vulnerability, and social crisis. Local people use their traditional knowledge to cope with various levels of crisis under vulnerable conditions, but sometimes doing so exceeds their capacity owing to the unwanted changes in climatic variables and knowledge gaps or uncertainties. Challenges on the basis of the problematic points should be noted, however, it would be more significant to achieve social sustainability under adverse climatic conditions.

## 1. Introduction

The natural system is overwhelmed by its own dynamism when anthropogenic activities interfere with it, whereas excessive amounts of external force are required to address its various abnormalities. In similar long term activities, nature is forced to balance intrusive action between human systems and ecosystems. Owing to climate change, natural system components, such as forests, floodplain areas, wetlands, and local management systems decline by millions of degree of effect each and every year (Flood Archive, 2004; Rahman and Rahman, 2015). Lower and lower-middle countries encounter more natural disasters, including rising sea levels, cyclones, coastal flooding, storm surges, and prolonged droughts (Nakashima et al., 2012; O'Brien et al., 2006; Thomalla et al., 2006; Ibarraran et al., 2009) owing to their strong dependence on natural resource extraction and also anthropogenic inhumanity, which may affect the environment, economy, and social development (UNISDR, 2008). Nowadays, climate change is a major factor causing natural events in the world. However, the magnitude and frequency of climatic disasters will be even more threatening in future decades. According to Climate Change Cell (2007),

* Corresponding author. Graduate Program in Sustainability Science - Global Leadership Initiative, Graduate School of Frontier Sciences, The University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa, Chiba, 277-8563, Japan.
*E-mail addresses:* rakibmamun_ju@yahoo.com, md.rakib@s.k.u-tokyo.ac.jp (M.A. Rakib).

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Bangladesh is one of the most climate-vulnerable countries in the world. A number of developing countries have been experiencing climatic hazards, and some unavoidable risks can lead to more loss of life and property damage. The erosion of river banks and land, and salinity intrusion severely affect local communities and biodiversity in Bangladesh (Seal and Baten, 2012; Alam et al., 2017), both of which may become more serious in the future (Pender, 2008; Wong et al., 2007). Perhaps, at least once a year, some of the natural disasters affecting Bangladesh will change how the damages function. In the coastal region of Bangladesh, cyclones are commonly associated with global warming. Meanwhile, other hydro-meteorological coastal disasters, including storm surges, water logging, and salinity intrusion in soil have increased, as have surface water and groundwater. Trends in increasing average temperatures, and the intensity and frequency of weather-related changes can be attributed to the influence of climate change (DFID, 2004).

Historically, between 1877 and 2009, a total of 159 cyclones including 48 severe cyclonic storms, 43 cyclonic storms, and 68 tropical depressions hit people in the coastal areas of Bangladesh (Sultana and Mallick, 2015). Approximately 50 million people, corresponding to almost one-third of the total population, live in its coastal areas (Miyan, 2009; Rahman, 2010). Ali (1999) reported that since 1970 the number of cyclones originating from the Bay of Bengal has decreased but their intensity has been augmented. Global Humanitarian Forum (2009) reported that the coastline and low-lying areas are highly exposed to both sea level rise and natural disasters, especially in the southern part of Bangladesh. Repeated occurrences of any natural hazard cause significant damage to the socioeconomic foundation of a society owing to impairment of livelihood. The United Nations International Strategy for Disaster Reduction (UNISDR, 2008) reported that disaster and climate change are interrelated issues; climate change could be added to the number and extent of disasters with more extreme weather events. Consequently, its negative impacts continuously and indirectly force change in coastal people's lifestyle and routine work, while social and situational factors increase vulnerability.

Moreover, salinity has been emerging as a serious threat in the coastal regions of Bangladesh. It may be caused by the impacts of climate change including cyclonic storm surges, the shortage of fresh water discharge from upstream, and the long duration of inundation in surface areas. During the dry season (November to March), saline water can influence factors upstream up to 240 km from the coast (Karsili et al., 2013), and can destroy the freshwater ecosystem. Owing to the salinity hazards, unavoidable risk has been raised in surface and subsurface waters. The high salinity directly inhibits coastal farming and aquaculture activities on which most communities depend. In fact, crop production in Bangladesh depends on surface water and groundwater, both of which are unusable for irrigation purposes. Owing to the effects of extreme salinity and diseases, the shrimp production rate has gradually declined in prospective coastal areas, while the crab productively faces a lot of challenges. In the dry season (November to March) particularly, salinity rises higher than the optimum conditions for shrimp culture. The high salinity and temperature as well as changes in rainfall patterns escalate the deterioration of water quality and the surrounding environment change that is attributed to outbreaks of shrimp diseases and death tolls. Other natural resources have gradually been confronting several categories of problematic factors whose risks may lead to an increase in devastating damages. In consequence, social insecurities have been raised for all components of the social strata.

Owing to the geophysical characteristics of the southern coast of Bangladesh, the poor socioeconomic status of the local people has become even worse insofar as it is affected by cyclones and storm surges (Alam, 2011). Gabura is a remote area of the Satkhira district. Nowadays, natural events such as cyclonic storm surges and their concomitant effects have created an unstable situation in local communities. The consistent interruption and uncertainty of coastal hazards inhibits local development efforts. Consequently, a number of questions arise regarding the changes in the regional environment and livelihood patterns, including what the major threats are, how the regional environment changes people's attitudes to development activities, and how these perceptions make things unexpectedly worse than before. Social perceptions may be a reliable factor in pointing to the long-term intervention of environmental change in local development. However, regarding climate change, people's perceptions are completely based on their personal experience and region-based, which is influenced by various factors (Niles and Mueller, 2016). Although people always try to reduce the social and livelihood risks using traditional knowledge, tools, and social techniques, unforeseen disruptions of natural events often create a gap between their experiences and actual coastal disasters.

Coastal hazards are intensifying the impacts in agriculture and aquaculture sectors while high salinity is considered a substantial threat to productivity and is creating a drinking water crisis in the vulnerable coastal areas of Bangladesh. This study aims to investigate the internal consistency in the local perceptions of the socio- and agro-environmental vulnerabilities that have not been clarified in the previous studies. It also needs to consider efficient levels of traditional knowledge to cope with the relevant impacts and, in some cases, climate uncertainties because most local communities have failed to save themselves using their practical experience alone.

## 2. Materials and methods

### 2.1. Study area

This study was conducted at the Gabura union in the Shymnagar Upazila and Satkhira districts located in the southwestern coastal region of Bangladesh (Fig. 1). It is a site that is highly vulnerable to coastal hazards like cyclonic storm surges and salinity problems, which mostly originate from the southern part of the Bay of Bengal. In Bangladesh, cyclones (e.g., Aila-2009, Nargis-2008 and Sidr-2007) have caused significant damage among the coastal communities, such as loss of life, property (Dube, 2009), and livestock. A large number of people are involved in agriculture, aquaculture, fishing, and mangrove forest-related livelihood activities. Major portion of the agricultural land has been converted into aquaculture farming (Fig. 1). The path of two of the

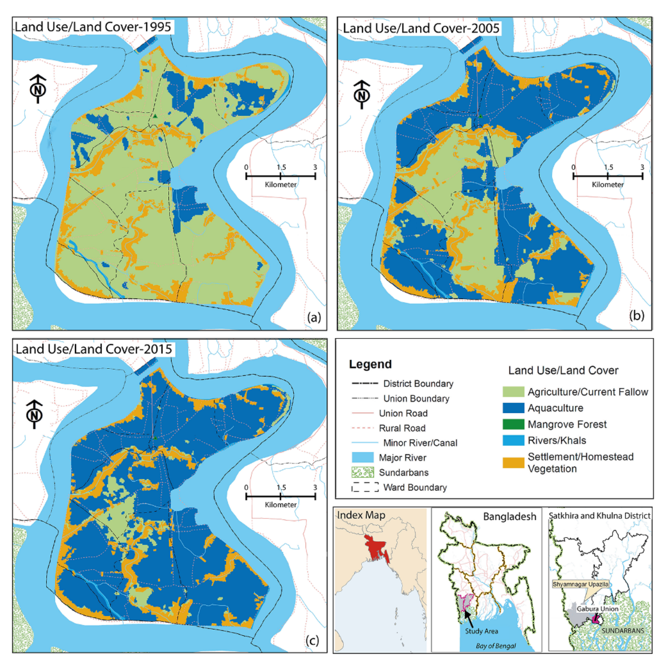


**Fig. 1.** Maps of the study area exhibiting the changing trends of land use pattern from 1995 to 2015 (Modified after UNDP, 2018).

major rivers, Kholpetua and Kobadak, encloses different sites of the union. Geographically, this area is considered to be a highly vulnerable and disaster-prone location, very close to mangrove forests and the Bay of Bengal.

### 2.2. Data collection

Methods of data collection consisted of a questionnaire survey, interviews and field observations. These techniques were intensively used to investigate the real scenarios, and conceptualize data collection in the field. A semi-structured questionnaire was formulated using open- and closed-ended questions to explore the situational crisis, social crisis, and traditional strategies for disaster risk reduction. The questionnaire was segmented into four sections: (1) general information about the local people, (2) coastal threats and impacts, (3) livelihood vulnerabilities depending on regional natural events and socio- and agro-environmental factors, and (4) traditional techniques for disaster risk reduction and perspectives on disaster management challenges. Likert scale (five scales) type questions were used to code the questionnaire data. A total of 149 questionnaires were collected among respondents (both male and female) who agreed to share their views. All questions were read to respondents in the local language. All information was collected using feedback forms, and some additional information was recorded by hand and later formatted in a data collection sheet. A total number of 32 principal variables were selected (Table 1). The variables reflected social issues, regional environmental changes, impacts, severe salinity hazards, and local initiatives to take the measures under adverse climatic conditions. These variables were used to evaluate the social vulnerability in terms of the changing status with time using multivariate statistics. Almost all the variables were selected from discussions with the local people.

Interviews were conducted with local businessmen, floating farmers, fishermen, honey collectors, day laborers, travelers, and some other unspecified people. Field observation was performed to understand the social problems in relation to research questions. These findings were helpful to verify the questionnaire results. The entire approach to data collection was implemented rigorously to maintain the importance of the study's findings and to fulfill the research goals. The database was organized according to the analysis and interpretative design while similar characteristics of the data were kept together so as to ensure the existing relationships among the variables were apparent. In addition, to conceptualize the relationship between social vulnerability, development crisis, and local knowledge uncertainty, each of the factors corresponding to the three components was gathered through interviews and field observations.

### 2.3. Multivariate analysis

Multivariate analysis, including principal component analysis (PCA) and cluster analysis (CA), were performed to examine the relationships, causes, and impacts of socio- and agro-environmental factors. PCA plays a significant role in identifying the associations between two variables by reducing database dimensionality (Helena et al., 2000). The associated variance among the variables expressed by the PCA eigenvalues and the total number of original variables' inclusion in the PCA are specified by the loadings, while the loading scores refer to the transformation of individual observations (Helena et al., 2000). CA identifies the similarities in regard to variable characteristics and classifications into several groups (Bhuiyan et al., 2010). Each of the groups contained a number of variables that exhibited strong internal homogeneity while two groups demonstrated high external heterogeneity (Shrestha and Kazama, 2007). A hierarchical agglomerative approach is the most common technique for expressing the relationship between variables or an entire set while Euclidean distance usually represents the distance between samples, typically explained by a dendrogram or tree diagram (McKenna, 2003; Otto, 1998). To find out the distance between two clusters, the wards methods were applied to investigate the analysis of variance approach, which is useful to reduce the Sum of Squares (SS) of any two clusters. PCA and CA are robust techniques to identify internal consistency among the local respondents' perceptions regarding the existing status of socio- and agro-environmental factors (Rakib et al., 2017). The statistical analysis was performed using the statistical package software SPSS (version 21) for Windows.

## 3. Results

### 3.1. Demographic profile

According to the questionnaire survey, the ratio of male to female respondents was 9:1 while the composition of age groups were 26.17% (21–35 years old), 50.34% (36–50 years old), 22.15% (51–65 years old), and 1.34% (66–80 years old), respectively. Seventy percent of respondents depend on daily basis work (day labor) while most of the others rely on services and local business. The average income of the local people was found USD 80.21 per month (in sample), which is considered the very poor socioeconomic condition. Moreover, approximately 45% of the respondents were found to be completely illiterate.

### 3.2. Local perceptions on environmental exposure

The negative consequences of environmental changes lead to unexpected events in the coastal areas of Bangladesh. Upward trends in climatic variables act as initiating factors in changing the overall climatic mode. Results showed significant variability in meteorological parameters, such as rainfall and temperature; in regard to local perceptions, a significant number of people (64.43%) believe that the seasonal trend of climatic parameters has been changing over a long period of time. According to the local opinion (87.25%), the cyclone is a principal hazard that caused other problems such as flooding, salinity and waterlogging across the area. High salinity conditions in all sorts of environmental components are considered a serious threat to coastal agro-economy, biodiversity, and human health. During the cyclonic storm surges, comparatively low land is being flooded regionally or on a larger scale.

The context of agricultural activities is considerably different from the eastern and northwestern regions of Bangladesh. High salinity in water bodies and soil is the main threat to productivity (see Fig. 2a). Basically, in the dry season (November to March), high salinity creates disastrous conditions owing to the shortage of rainfall. Most farmers

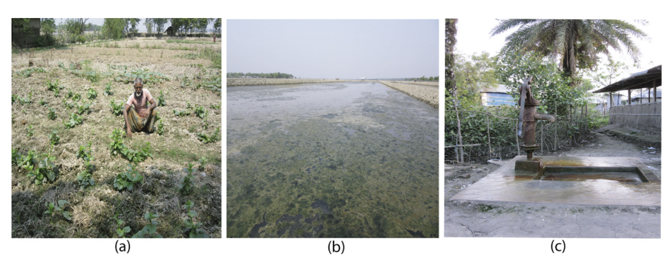


**Fig. 2.** The vulnerability status of drinking water, aquaculture and agricultural activities. Fig. (a) Indicates the coastal agricultural activities while local farmers face productivity challenges because of the increasing trend of soil salinity during the summer season, but in the rainy season soil salinity declines a little, which is not suitable for better production rate. Fig. (b) Demonstrates shrimp *gher* that is full of phytoplankton bloom, which is not supportive of sustainable aquaculture practices. It can occur due to the overuse of inorganic fertilizer, chemicals and high salinity conditions. Fig. (c) Tube-well water has high salinity problem which is unsuitable for drinking purposes. Coastal people use local rainwater harvesting techniques and local pond water to meet their household potable water demand (Source: Author).

claimed that soil salinity (74.50%), flood impacts (71.81%), storm surges (77.85%), and groundwater crises (88.59%) are significant concerns for the continuation of crop cultivation and rates of production. According to the local respondents, a large number of farming problems like soil fertility, water-retention capacity, root and stem damage, and diseases are concomitantly influencing the cropping pattern of farming land. One of the key (a political leader) respondents stated that "10–15 years ago, we produced different crops around the Gabura area but nowadays it is almost unsuitable for crop cultivation due to excess levels of salinity in the soil, which apparently have become severe since Cyclone Aila in 2009." Another farmer reported that "we depend on nature for our cultivation. In the rainy season, the soil salinity level decreases a little but does not reach a suitable level for cultivation. Sometimes, we cannot think about how we can select cultivation techniques owing to frequent threats of hazard". Climate abnormality may force changes in any situation involving climatic standards and their balance. It is one of the major causes of livelihood and socioeconomic crisis. The majority of the respondents stated that "day by day, soil salinity is increasing while the cultivation rates are decreasing. We are day laborers and may lose our work. So how can we support our families?".

Fisheries, including shrimp farming and fishing activities are one of the principal income sources of the people in Gabura. During the field observations, 73% of peoples reported that shrimp farming is going to face innumerable threats because of an increase in water temperature and salinity. Most of farmers reported that shrimp farming activities were hampered because of uncertainties in climatic parameters, such as changes in rainfall patterns (55.03%) and high temperatures (69.80%). In addition, climate change, natural events, disease outbreaks, unexpected deaths, flood impacts, storm surges, high water temperature, antibiotics, phytoplankton blooms, rainfall shortages, and exotic species induced many different challenges for culture, production, and timely harvests (see Fig. 2b).

### 3.3. Drinking water shortage

Salinity intrusion in the coastal aquifer is the biggest challenge to ensure potable water at the household level among the Gabura communities. It was observed that there was almost no fresh water source in the adjacent region of the coastal belt. Most people (95%) reported that they use pond and contaminated tube-well waters for drinking (see Fig. 2c). Approximately 85% of the respondents stated that they drink water from the pond directly without any physical or chemical treatment because of a lack of treatment facilities. Rainwater harvesting is a principal and important source of water for drinking purposes in the coastal areas. One of the local respondents reported that "We always try to collect rainwater during the rainy season for drinking and cooking purposes in an attempt to best prepare ourselves for an upcoming water crisis. However, sometimes we cannot afford to preserve enough rainwater for the future water crisis".

### 3.4. Livelihood susceptibility

Local livelihoods are greatly affected by environmental change through loss of agricultural production, livestock, and natural resources extraction (see Fig. 3). More than 79% of people depend on fishing and aquaculture-related livelihoods, and their wellbeing depends on increased productivity, daily income, and the market price of products, such as freshwater fish and shrimp. According to local opinion, shrimp and crab cultivation are not as good as before in terms of productivity and profitability. In some cases, productivity decreases are caused by coastal hazards and environmental stresses, thus families may suffer food crises and malnutrition. Livestock resources will be affected if the environmental changes gradually increase. Owing to the loss of production, businessmen and traders will be affected in ways that disrupt their businesses, capital, and income.

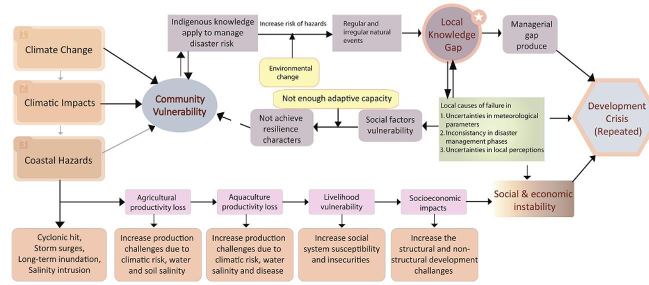


**Fig. 3.** The status of climate change scenarios, coastal disaster, livelihood vulnerabilities, social insecurities, and development crisis in the coastal community. The conceptual diagram reflects the overall consequences of coastal hazards and the effectiveness of traditional knowledge to cope with disaster impacts. The uncertainties in meteorological parameter increase disaster intensity, frequency, and magnitude. But it is ostensibly a serious problem to understand the forthcoming disaster consequences using traditional knowledge (Source: Author).

### 3.5. Investigation of consistency in local perceptions using multivariate analysis

A multivariate analysis consisting of principal component analysis (PCA) and cluster analysis (CA) was performed to measure the consistency in local perception on coastal vulnerability and its associated hazards.

#### 3.5.1. Principal component analysis

Principal component analysis (PCA) is a technique that reduces a large number of variables into a small number of major variables according to their quantity and influence (Shrestha and Kazama, 2007). PCA demonstrates the individual potentiality of variables and their significance level in samples. PCA was carried out on socio- and agro-environmental components to assess the significance level of dominance in the coastal part of Bangladesh and how these components are associated. Three principal components were derived with the consideration of standard eigenvalues (exceeded 1) that extracted 98.678% of the total variance as shown in Table 1. The loadings score were divided into three classes of strong (> 0.75), moderate (0.75–0.50) and weak (0.50–0.30) respectively (Liu et al., 2003; Gao et al., 2016; Wang et al., 2017). The first principal component (PC1) explains 68.80% of the total variance as it covers a significant level of positive loading of SLS (0.992), SWT (0.994), ATC (0.997), IFU (0.987), SIF (0.998), RDC (0.914), SDC (0.920), UDC (0.998), CGR (0.997), CPR (0.919), GS (0.992), SFCR (0.987), CCI (0.999), CH (0.993), SD (0.991), DSJ (0.983), RFI (0.996), SSI (0.997), ACS (0.985), WBG (0.987), SLSG (0.994) and RRC (0.855); moderate positively loaded of ES (0.703); and weak positively loaded of SCP (0.490) and EXS (0.411) (see Table 1 for the meaning of parameters). A rotation matrix plot exhibits the significant associations among the more connected environmental and social components (see Fig. 4). The second principal component (PC2) explains 20.433% of the total variance, and is loaded with a significant level of strong positive loadings of SFC (0.984), ICS (0.976), SCP (0.860), AWR (0.996), AWQ (0.950) and EXS (0.889); moderate positively loaded of ES (0.690); weak positively loaded of SDC (0.377) and STC (0.437). The third principal component (PC3) explains 9.445% of the total variance, strong positively loaded of WHC (0.875), STC (0.872) and OMW (0.999); weak positive loadings of CPR (0.324) and RDC (0.358). This assists in identifying the relationships among the variables, which is helpful when planning actions or measures with respect to the socio- and agro-environmental parameters.

#### 3.5.2. Cluster analysis

Cluster analysis (CA) is a useful means of identifying relationships among a large number of social variables. Usually, CA helps to divide a

**Table 1**
Rotated components and loadings scores of PC1, PC2 and PC3.

| Parameters | Code | PC1 | PC2 | PC3 |
|---|---|---|---|---|
| Salinity Level in Soil | SLS | 0.992 | 0.024 | −0.125 |
| Surface Water Temperature During Summer | SWT | 0.994 | 0.077 | −0.067 |
| Atmospheric Temperature Change | ATC | 0.997 | 0.053 | 0.002 |
| Water Holding Capacity Loss in Soil | WHC | −0.204 | 0.169 | 0.875 |
| Soil Fertility Change | SFC | −0.129 | 0.984 | 0.123 |
| Inorganic Fertilizer Using Pattern in Farm | IFU | 0.987 | 0.124 | −0.048 |
| Average Surface Area Inundation Frequency | SIF | 0.998 | −0.018 | 0.050 |
| Saline Tolerant Crops Cultivation Status | STC | −0.047 | 0.437 | 0.872 |
| Root Damage Problems of Crop | RDC | 0.914 | 0.186 | 0.358 |
| Stem Damage Problems of Crop | SDC | 0.920 | 0.377 | 0.097 |
| Unexpected Diseases of Crops | UDC | 0.998 | 0.001 | −0.06 |
| Crop Growth Rate Impacts | CGR | 0.997 | 0.054 | −0.045 |
| Crop Production Rate Impacts | CPR | 0.919 | −0.001 | 0.324 |
| Groundwater Scarcity | GS | 0.992 | −0.016 | −0.119 |
| Initiatives to Control Saltwater Intrusion | ICS | −0.155 | 0.976 | 0.115 |
| Shrimp Farming Crisis | SFCR | 0.987 | 0.083 | −0.129 |
| Climate Change Impacts | CCI | 0.999 | −0.029 | 0.014 |
| Cyclone Hit | CH | 0.993 | −0.011 | −0.111 |
| Shrimp Diseases | SD | 0.991 | −0.001 | −0.122 |
| Death Rate of Shrimp Juveniles | DSJ | 0.983 | 0.145 | −0.089 |
| Regional Flood Impacts | RFI | 0.996 | −0.005 | −0.076 |
| Storm Surge Impacts | SSI | 0.997 | −0.031 | −0.07 |
| Antibiotic and Chemical Use in Shrimp Gher | ACS | 0.985 | 0.160 | −0.034 |
| Water Bloom in Shrimp Gher | WBG | 0.987 | 0.004 | −0.154 |
| Salinity Level in Shrimp Gher (Summer) | SLSG | 0.994 | 0.070 | −0.059 |
| Regional Rainfall Pattern Change (Uncertainty) | RRC | 0.855 | 0.482 | −0.132 |
| Shrimp and Crab Production Rate | SCP | 0.490 | 0.860 | 0.014 |
| Observational and Monitoring Work | OMW | 0.025 | 0.005 | 0.999 |
| Average Weight loss Rate (Shrimp and Crab) | AWR | 0.030 | 0.996 | 0.064 |
| Average Water Quality in Shrimp Gher | AWQ | −0.182 | 0.950 | 0.250 |
| Exotic Species in Shrimp Gher | ES | 0.703 | 0.690 | 0.081 |
| External Support (Aid or Financial Support) | EXS | 0.411 | 0.889 | 0.027 |
| Eigenvalues | | 22.016 | 6.539 | 3.022 |
| % of Variance | | 68.80 | 20.433 | 9.445 |
| Cumulative % | | 68.80 | 89.233 | 98.678 |

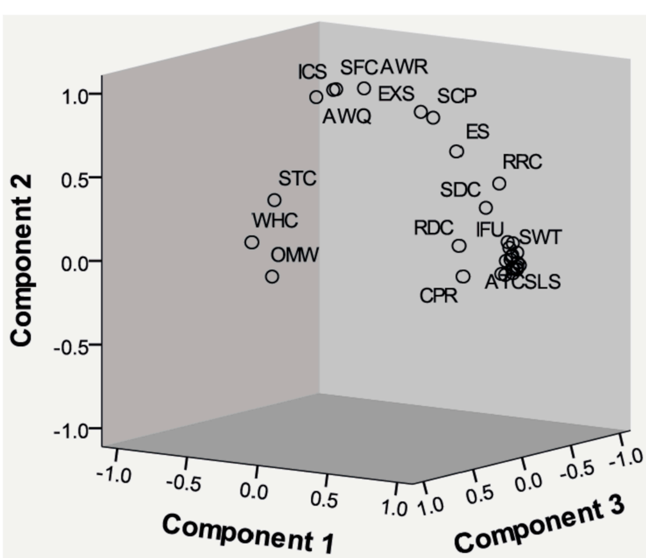


**Fig. 4.** Loading score plot between PC1, PC2, and PC3.

population into different groups according to similar characteristics of a set of data that may express causes, impacts, or the source of any unidentified social problems. CA was performed using socio- and agro-environmental parameters to identify the overall status of regional

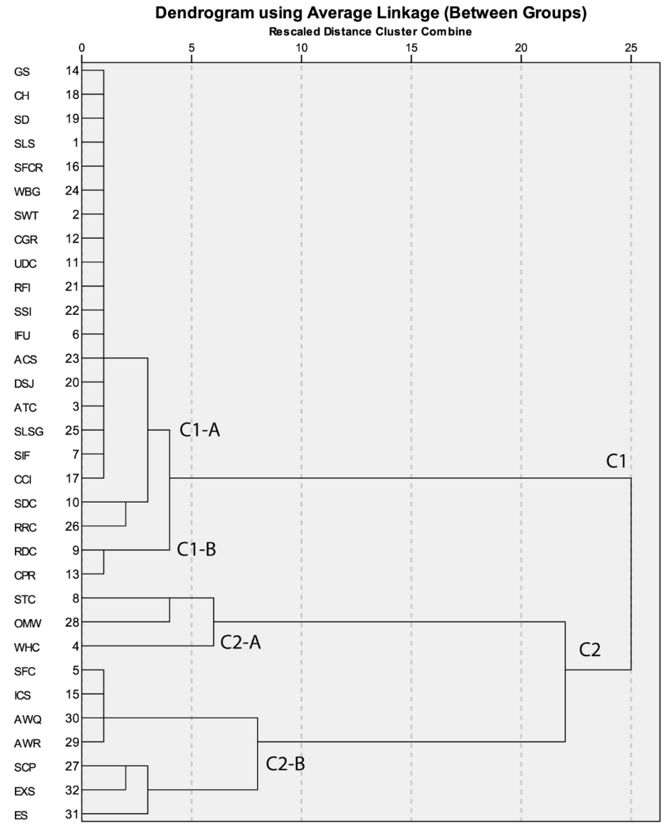


**Fig. 5.** Dendrogram representing the different cluster in regards to Ward's method using Euclidean distance.

change, and how environmental stresses affect social development. As shown in Fig. 5, all the variables were divided into two major groups: cluster-1(C1) and cluster-2 (C2). C1 consists of two sub-clusters of C1-A and C1-B; C1-A consists of C1-A1 (GS, CH, SD, SLS, SFCR, WBG, SWT, CGR, UDC, RFI, SSI, IFU, ACS, DSJ, ATC, SLSG, SIF and CCI) and C1-A2 (SDC and RRC), and C1-B consists of RDC and CPR. C2 consists of the other two sub-clusters of C2-A (WHC, OMW, and STC) and C2-B. C2-B consists of two sub-clusters of C2-B1 (SFC, ICS, AWQ, and AWR) and C2-B2 (SCP, EXS, and ES).

### *3.6. Local knowledge uncertainty*

Tropical cyclones are accompanied by storm surges, which is the most common disaster in the coastal zones. Although a set of measures was taken against cyclonic storm surges by their own capacity, however, this appears to be insufficient currently. A key informant stated that "Basically, we always try to reorganize the community people to make them aware of the importance of taking time-evacuation measures under any adverse climatic conditions. However, now it is not always possible due to a lack of advanced technology, methods of information dissemination, individual communications, sound road network system, and people's wiliness to change. Sometimes, we fail because of uncertainty in cyclonic trends, a short notification period, and missed communication with local people".

In Bangladesh, indigenous knowledge is generally more effective in the char land and the floodplain areas to reduce the disaster risk. According to local people, elderly people help to reduce disaster risks by sharing their previously acquired knowledge on regional status, topographical change, disaster frequencies, trends, and intensity, and how the regional environment has changed. Sometimes, using their guidance, local people try to understand the present situation and mitigate the major impacts, including floods, cyclones, storm surges, and

salinity hazards. One of the respondents reported that "Nowadays, we cannot realize the upcoming disaster because of the changing mode of cyclonic trends discontinuation. For example, during the cyclonic storm, Aila in 2009, not a single person in our community understood its ferociousness because within one hour all of the surface land and residential area were inundated with overflowing water. We did not get enough time to save our property, livestock, and life; thus many of our neighbors died. I had lost my three family members (my wife, younger daughter, and son). It was a nightmare for the Gabura community. We will never forget …".

### 3.7. Economic impacts and support

A number of scholars have discussed the social impacts of shrimp aquaculture in regard to economic and environmental impacts (Primavera, 1997, 2006; Neiland et al., 2001; Alam et al., 2005; Costa-Pierce, 2008; Paul and Vogl, 2011). Sometimes, environmental instability forces a shift or interruption in the regional or national development through breaking the chain of development components. Climate shocks and their adverse effects lead to creating vulnerability among the poor people in the world owing to their implications for social, economic, and development activities (IPCC, 2012). Approximately 79% of respondents reported that they are frustrated because of the interruptions and instability created in their regular farming, fishing, and aquaculture activities. In addition, high salinity and its resultant diseases have gradually increased, which may cause large-scale production declines in the near future and lead to crises among day laborers dependent on the daily work available in the shrimp farming fields and the agro-farming sectors. Moreover, a major part of the coastal land is owned by multinational and national investors in Bangladesh (Deb, 1998; Ito, 2002), thus 85% of the investors come from outside the local area (Ito, 2002).

Social capital generally differs from coastal to urban, and from rural to char-land areas in Bangladesh. In the coastal community, social capital is reduced by coastal disasters and their impacts on livelihood, while the household economy of people in rural, coastal, and char-land areas is more vulnerable than that of those in mainland Bangladesh. Some governments (GOs), non-government organizations (NGOs), donor agencies, and the local union *parishad* (council) have taken initiatives to secure the socioeconomic status of coastal communities through credit support (Pokrant and Bhuiyan, 2001). NGOs try to support local people in the alleviation of poverty and community development before, during, and after the periods of disasters. Sometimes, they try to highlight building the community's resilience against the disaster and the measures to alleviate it. NGOs have attempted to circulate disaster-related information among local people, including disaster preparedness, local adaptation strategies, mitigation, recovery, and construction. Credit support and a small loans system also assist the Gabura people in developing their household economy. Moreover, raising livestock is another important project, which may help to develop resilient livelihoods.

## 4. Discussion

### 4.1. Consequences of environmental exposure

A number of climatic risks have been associated with the rising sea level, increase in the magnitude of cyclones, changes in the pattern of rainfall, and increases in drought, coastal flooding, sea-surface temperature, and salinity (Ahmed, 2013). Consequently, local environmental instability adversely impacts on productivity in agriculture and aquaculture sectors. In Bangladesh, people are directly or indirectly involved in agricultural activities. The crop production rate in the coastal part of Bangladesh is much lower than that in other parts of the country (BBS, 1996). Around 1.05 million ha of land are directly affected by soil and water salinity in the coastal regions of Bangladesh (Sikder, 2013) and this could increase to 2 million ha by 2050 (Conway and Waage, 2010). Frequent storm surges and flooding may be the causes of increasing levels of salinity in the soil.

The salt accumulations in the root zone and crop growth are hindered by saline soils (American Society of Civil Engineers, 1990; Karim et al., 1990; Somani, 1991). Water quality has been progressively deteriorating owing to irregular changes in physical and chemical parameters produced by a mix of foreign substances (e.g., inorganic and organic contaminants), saltwater, and debris materials. An increase in water temperature under climate change also damages aquatic organisms and their living conditions. At least minimum living standards and water quality must be ensured to sustain shrimp larvae from the juvenile stage to the maturation stage. Based on the people's perceptions, rainfall uncertainty and long dry conditions at specific periods in the year directly contribute to enhancing salinity in the shrimp farming areas. Owing to these effects, shrimp production rates are falling to levels at which it is not cost-effective to continue encouraging farmers to farm further. Alam et al. (2017) reported that 25% of shrimp species and 12% of marine fish have disappeared because of high salinity. Although local communities always try to change their traditional strategies to prawn and shrimp farming in response to climate change impacts, the production rates are not profitable. If it is possible to satisfy the communities' demands, it would be helpful to build up resilient communities. Unplanned and inappropriate processes of aquaculture are also a big challenge threatening human sustenance in the Gabura areas. Aquatic biodiversity of the coastal regions is greatly influenced by the unplanned saline water intrusion into fresh land for shrimp *gher* (pond). These impacts ultimately accelerate the changing patterns in the natural system, such as its physical processes, the aquatic and terrestrial environments, deforestation, biodiversity, and ecosystems (Rahman et al., 2013). The shrimp and crab farming sectors may contribute to developing the sound local socioeconomic status. Ahmed and Diana (2015) reported that more profit and foreign currency could speed up the peace of local development in the local environment.

People frequently face the threat of drinking water scarcity (Rahman et al., 2017) and lack of fresh water for household activities. At this time, the drinking water scarcity appears as a severe problem among the coastal communities (Talukder et al., 2016). Moreover, groundwater contains a high level of salinity that is detrimental to health. Salinity in groundwater is higher than that in pond water while even pond water may lead to pathogenic contamination. Reservoir (e.g., pond or open concrete-built tank or round ditch) water quality is also not hygienic for drinking purposes because it contains different debris materials and contaminants. The local people always try to harvest rainwater, but the maintenance of a large volume of the water harvest is quite difficult owing to regional rainfall uncertainties, financial problem, difficulty in the collection process, insufficient storage capacity, and large individual and family demands. In this situation, it is difficult to manage the water crisis without implementing any substantial new initiatives, such as fresh water supply to the Gabura community.

The long-term consequences are major threats to the coastal community's livelihood patterns and sustenance. Gradual climate change impacts lead to decline in the normal functions and work activities in the fishery and agriculture sectors and, as a result, people tend to leave the sectors to secure their livelihood. Because of the effects of shrimp diseases, cyclones, and market failure, aquaculture-based livelihoods have declined (Shameem et al., 2014). As a result, some individuals try to change their existing livelihood to ones that will ensure a higher income, and social and food security. A number of people tend to migrate to comparatively high-income areas, such as cities and towns, for a better lifestyle. Accordingly, in some areas of the country, some people are employed as construction workers, industrial workers, rickshaw pullers, brickfield workers, and in other temporary jobs.

### 4.2. PCA and perceptional consistency

Regarding the PC1, the largest number of components, including SLS, SWT, ATC, IFU, SIF, RDC, SDC, UDC, CGR, CPR, GS, SFCR, CCI, CH, SD, DSJ, RFI, SSI, ACS, WBG and SLSG are closely associated with cyclone hit, storm surges, climate change and its related hazards (Table 1). Those impacts have extremely damaged the local environment and livelihood sectors. According to PC2, all of the variables, including aquaculture and agriculture sectors, are affected by the impacts of coastal hazards, such as high salinity hazards and climate change. PC3 represents the measures in the adverse disastrous situation, such as introducing salinity-tolerant crops and regular impact monitoring. Mostly, PC1, PC2, and PC3 have explored the coastal hazards, productivity impacts, and measures-related component loadings, respectively.

### 4.3. CA and perceptional consistency

According to C1-A1, climate change may enhance regional climatic impacts alongside an increase in salinity in surface and sub-surface water bodies, shrimp *gher*, and the coastal aquifer during the summer season (March to May). And it also can associate with cyclonic storm surges and long-term inundation problems. C1-A2 exhibits another influential factor (RRC) that may affect the crop growth and productivity. The cluster C1-B, consisting of RDC and CPR, represents the correlation between root damage and crop productivity. Both C1-A2 and C1-B can have greater influence to insecure the agricultural productivity because of the uncertainty of rainfall and high salinity condition in the soil. The cluster C2-A, combined with the three factors, can define the social and scientific measures in adverse situations, including the type of salinity-tolerant crops that would be suitable for improving the production rate, the present status of the water-holding capacity in the soil, and the observational and monitoring status of these issues. The four components (SFC, ICS, AWQ, and AWR) are assembled as sub-cluster C2-B1 and are mostly interlinked with hard and soft measures to protect saltwater intrusions in plains land. Hard measures may also strongly influence soil fertility, shrimp farming water, and its growth rate. In addition, the last sub-cluster C2-B2 shows a strong relation between shrimp and crab production rates, and external supports and exotic species. It may reveal that shrimp and crab production rates depend not only on the regional environmental crisis but also on the socioeconomic well-being or external support received in terms of proper care and cultivation. CA results revealed the impacts of salinity contamination and how they spread in the coastal areas of Bangladesh. Agriculture, and shrimp and crab productivity are primarily associated with climatic impacts, water quality, and salinity hazards. Depending on salinity level fluctuations, the degree of contamination can change natural systems. The agro-environmental hazards are associated with social risks that may inhibit consistent activities in the coastal community.

### 4.4. Benefits of PCA and CA

People's perception of social and environmental factors may vary depending on several aspects of human lifestyle. To identify the environmental change and livelihood impacts, PCA and CA tools may be used to explore the consistency in local perceptions regarding the measured factors. In Bangladesh, as principal threats, cyclones lead to the change in the surface and subsurface environments and social systems in the coastal community. For example, cyclonic storm surges lead to long-term inundation and flooding that causes high salinity problems in the soil, surface water bodies, and groundwater bodies. Those impacts may lead to the socioeconomic and social crisis at the coastal belt of Bangladesh. The question following this is to inquire "how the phenomena are understood by the coastal communities, such as the extent of damage and effect on livelihood?" This query can provide insights into the situational and social crisis in many cases. Local people can explain their observations through the narration of real-life experience, duration of residence time and insights. For this portion of the study, a number of variables were used to assess coastal hazards and livelihood impacts through analysis of perceived knowledge. PCA results show that there are significant positive loadings of many of the variables drawn in the first principal components, which are closely associated with coastal hazard impacts. Accordingly, based on the local perception, CA results explain the social and environmental factors and how they are associated or interlinked with each other. The responsible and consistent factors identified through the different groups in measured variables expressed consistency in perceived knowledge in coastal communities.

Most of the identified social and environmental variables are interconnected in relation to social development issues while coastal disasters are considered as principal and chronic constraints that inhibit socioeconomic growth. All of the variables are directly or indirectly affected by coastal hazards. Measured variables correlate with each other, and may influence coastal development issues. Local perception may play a vital role in identifying the possible solution while the proper data management and interpretation techniques can provide more applicable solutions. In this case study, findings in PCA and CA may contribute significantly to tackling vulnerable situations with proper decision making, planning, and long term policy approach.

### 4.5. Social consequences

Despite the outcomes of formidable disasters, people in Bangladesh adopt different disaster risk reduction strategies. These strategies have been traditionally practiced in the disaster-prone regions. The uncertainty of climatic variables leads to unexpected events that are evaluated as principal knowledge gaps among the communities (see Figs. 3 and 6). Sometimes local people do not realize the possible coastal threats that can arise, and their impacts. Sites that experience regular cyclonic storms increase the loss of life and property. They can hinder the achievement of sustainable development in this disaster-prone area of Bangladesh.

Normal development pathways are regularly interrupted by the socioeconomic factors that affect them owing to the unwanted changes in climatic variables, and devastating hazards like cyclonic storm surges and salinity intrusion. The consequent reduction in income levels and livelihood instability leads to a gradual loss of social capital as socioeconomic growth plays a key role in regulating social capital. The coastal environmental crisis may cause food insecurity, a crisis in livelihoods, and diseases that promote the disruption of social components. Nowadays, coastal people are gradually losing their household assets and social capital owing to those disasters. Moreover, rural communities are failing to save money and other resources to meet urgent basic needs. Penury and destitution limit the development of

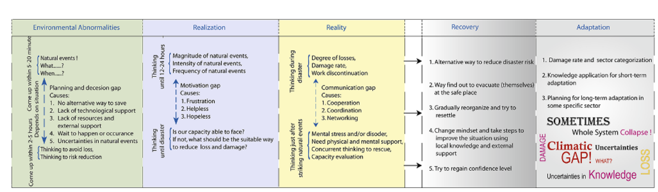


**Fig. 6.** The traditional disaster risk reduction techniques and internal knowledge gaps among coastal communities. The whole process has been divided into five phases of disaster response to adaptation such as environmental abnormalities, local realization, reality, recovery, and adaptation stage. This diagram is designed based on respondents' perception and field observation, how the local people think about the upcoming disaster and possible measures considering their insight, and experience. In most of the cases, local people strongly face disastrous consequences and try to mitigate negative impacts of coastal hazards, but uncertainties in meteorological parameters may lead to more death and property loss in the near future (Source: Author).

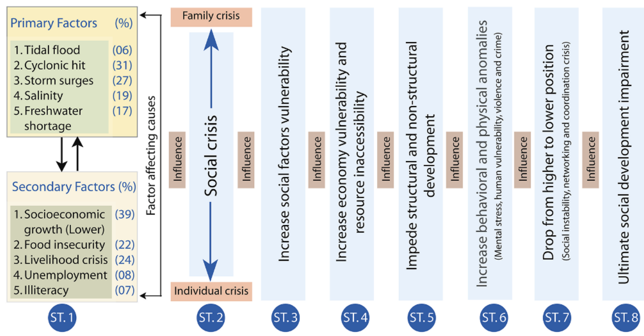


**Fig. 7.** The two types of factors (primary and secondary) that trigger social and local development crisis alongside the coastal belt of Bangladesh. During field observations, both potential factors were identified as the principal constraints to individuals and family crisis. These factors relate to individual or particular communities, socioeconomic conditions and developmental aspects. Thus, natural events and its consequences may alter current social systems. The progressive impacts influence each of the components in a society, whereas all of the steps (ST.1 to ST.8) are interlinked with social development stages (Source: Author).

social capital.

Shrimp aquaculture has also caused serious social problems, such as theft, robbery, murder, and rape, etc. in the coastal community (Shindaini and Baqui, 2012). Social problems, such as violence, theft, and robbery, etc., increase in a poor economy, while social bonding, family education, and institutional education, cannot resist these inevitable risks; in turn, these may lead to household crises and social instability (see Fig. 7). Population migration or downward social mobility is substantially attributable to vulnerability in livelihoods, food insecurity, poverty, and loss of physical and environmental functions. In some cases, people tend to migrate from the countryside to comparatively developed areas or nearby towns to obtain further income. Paul and Routray (2010) reported that on the mainland of the Barisal district, an average 27% temporary migration rate existed among cyclone-affected communities. Moreover, while all of the communities are not willing to migrate, a number of respondents wanted to migrate to obtain a better future and opportunities for their children. As a result, the population density of developed towns and cities has increased.

### 4.6. Challenges to enhance development

The people in the Gabura area frequently face a number of different challenges to enhance social development that should be taken into consideration.

- A large number of people were found to be illiterate (approximately 45%). Thus the illiteracy rate must be taken into consideration for the Gabura to maintain their way of life under adverse and hazardous conditions. It should be better to organize PFM (Participatory Action to Future Skill Management) program (Rakib et al., 2017) among the coastal communities to minimize the case (e.g. hazards) specific knowledge gap, which can accelerate social development trends in adverse coastal environmental crisis.
- Socioeconomic growth is considered the principal component for upgrading social development. Given the regular trends in environmental threats, existing livelihood strategies seem insufficient to maintain reliable economic sustainability. Alternative activities could act as a sustainable pillar to achieve socioeconomic sustainability at the community level.
- Food insecurity is one of the major challenges faced by coastal disaster. The ultimate consequences of coastal disasters have created poverty because of losses of production, income-generating sources, and livelihoods, and loss of and damage to resources. These outcomes should be especially taken into consideration and treated with special care to ensure the sustainability of local development.
- In the coastal area, social security has become more precarious because of the regular incursions of natural disasters, which have increased vulnerability, anxiety, and disastrous situations among the Gabura communities. These disasters should be regarded as basic threats to people and their daily activities. The described thematic outline could act as a guide to addressing the situational problem by implementing emergency management policies.
- Shrimp aquaculture is focused on a production-oriented concept in the Gabura region. Because of salinity contamination, the maximum amount of available land has been used for shrimp farming rather than agricultural activities. In this case, this reversed livelihood pattern, and hence livelihood instability have triggered further problem in securing a stable lifestyle.

Identifying an adaptation and mitigation strategy is a genuine challenge for ensuring social sustainability in a regional crisis. Social and situational factors have caused the problems, but the climatic uncertainties that can cause even worse future conditions can be partially averted with the non-structural and traditional knowledge practices used in the communities. Crisis-based practical knowledge practices may enhance people's skill in improving their traditional risk reduction strategies. In terms of climate change and societal aspects, most scholars have clearly emphasized the research on practices for adapting to vulnerability (Füssel and Klein, 2006). Adaptation policy and vulnerability research have received top priority compared to other disaster management components (Hinkel, 2011). Some organizations have been trying to develop a disaster risk reduction strategy and adaptive capacity among the Gabura communities in Bangladesh. The interaction between the organization and people should be developed through experience, knowledge and information sharing, disaster-related training, and special education programs on a regional scale.

## 5. Conclusions

This study undertook the exploration of the overall facts associated with climate change impacts according to social views, environmental impacts, and the socioeconomic conditions of the Gabura communities. In this era, environmental abnormalities are considered one of the more common and threatening issues to human sustainability. On the whole, increases in environmental consequences force people to become more susceptible to geographical position and changes in socioeconomic growth. In Bangladesh, coastal hazards and their impacts lead to inevitable menace, and continued loss of life and property. Depending on the observation, the coastal communities appear to experience more disasters than previously along with the negative influence of regional environmental changes, such as salinity intrusion. Regarding the local perceptions, owing to the climate change and tropical cyclone, livelihood sectors are severely affected, which make it more vulnerable to the socioeconomic structure. They were always struggling with making a livelihood and having to seek money to meet their daily basic needs. Nowadays the income-generating source, such as shrimp or agro-farming, is severely affected by adverse climatic abnormalities, salinity problems, and disease outbreaks.

Drinking water vulnerability was identified as one of the most health-threatening crises while a large number of people were directly exposed to other potential health risks and diseases. The multivariate analysis (PCA and CA) showed that local perceptions help to examine the coastal community's vulnerability despite the fact that most people experienced environmental susceptibilities, livelihood crises, and social insecurities. These findings would be helpful to explore new guidelines to establish policy dimensions of the crises, and in the future planning and possible policy-making to achieve social development and sustainability. This study suggests that it is also essential to learn more about the critical aspects of salinity intrusion problems and how they affect local socioeconomic status considering that many of the local

people have been encountering health problems caused by drinking water contaminated by salt.

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## References


Ahmed, N., 2013. Linking prawn and shrimp farming towards a green economy in Bangladesh: confronting climate change. Ocean Coast. Manag. 75, 33–42.

Ahmed, N., Diana, J.S., 2015. Coastal to inland: expansion of prawn farming for adaptation to climate change in Bangladesh. Aqua. Rep. 2, 67–76.

Alam, K., 2011. Mode of adaptation of coastal dwellers: the Case of Bangladesh. Man. Dev. 33 (3), 91–112.

Alam, M.Z., Carpenter-Boggs, L., Mitra, S., Haque, M., Halsey, J., Rokonuzzaman, M., Saha, B., Moniruzzaman, M., 2017. Effect of salinity intrusion on food crops, livestock, and fish species at Kalapara coastal belt in Bangladesh. J. Food Qual. 1–23.

Alam, S.M.N., Lin, C.K., Yakupitiyage, A., Demaine, H., Phillips, M.J., 2005. Compliance of Bangladesh shrimp culture with FAO code of conduct for responsible fisheries: a development challenge. Ocean Coast. Manag. 48, 177–188.

Ali, A., 1999. Climate change impacts and adaptation assessment in Bangladesh. Clim. Res. 12, 109–116.

American Society of Civil Engineers (ASCE), 1990. Agricultural Salinity Assessment and Management. ASCE Manuals and Reports on Engineering Practice. No 71, New York, NY 10017, USA.

BBS [Bangladesh Bureau of Statistics], 1996. Statistical Yearbook of Bangladesh, Statistical Division. Ministry of Planning, Dhaka 1000, Bangladesh.

Bhuiyan, M.A.H., Parvez, L., Islam, M.A., Dampare, S.B., Suzuki, S., 2010. Heavy metal pollution of coal mine-affected agricultural soils in the northern part of Bangladesh. J. Hazard Mater. 173, 384–392.

Climate Change Cell, 2007. Bangladesh and Climate Change, Climate Change Cell, Department of Environment, Government of the People's Republic of Bangladesh. http://www.bdresearch.org.bd/home/climate_knowledge/cd1/pdf/Bangladesh%20and%20climate%20change/Climate%20change%20impacts%20,vulnerability,%20risk/Climate%20Change%20And%20Bangladesh.pdf.

Conway, G., Waage, J., 2010. Science and Innovation for Development. UK Collaborative on Development Sciences, London.

Costa-Pierce, B., 2008. An ecosystem approach to marine aquaculture: a global review. In: Soto, D., Aguilar-anjarrez, J., Hishamunda, N. (Eds.), Building an ecosystem approach to aquaculture, FAO/Universitat de les Illes Balears Expers Workshop, 7-11 May 2007, Palma de Mallorca Spain, FAO Fisheries and Aquaculture Proceedings No. 14. Food and Agriculture Organization of the United Nations (FAO), Rome, pp. 81–115.

Deb, A.K., 1998. Fake blue revolution: environmental and socio-economic impacts of shrimp culture in the coastal areas of Bangladesh. Ocean Coast. Manag. 41, 63–88.

DFID [Department for International Development], 2004. The Impact of Climate Change on the Vulnerability of the Poor. The Key Sheet 03. DFID, UK Available at: https://www.unpei.org/sites/default/files/PDF/resourceefficiency/KM-resource-DFID-impact-climatechange-vulnerability.pdf, Accessed date: 7 August 2018.

Dube, S.K., 2009. Recent Developments in Storm Surge Prediction in the North Indian Ocean. http://nidm.gov.in/idmc2/PDF/Abstracts/Cyclone.pdf.

Flood Archive, 2004. Global Register of Major Flood Events. http://www.dartmouth.edu/floods/Archives/2004sum.htm, Accessed date: 7 October 2018.

Füssel, H.M., Klein, R.J.T., 2006. Climate change vulnerability assessments: an evolution of conceptual thinking. Clim. Change 75, 301–329.

Gao, L., Wang, Z., Shan, J., Chen, J., Tang, C., Yi, M., Zhao, X., 2016. Distribution characteristics and sources of trace metals in sediment cores from a trans-boundary watercourse: an example from the Shima River, Pearl River Delta. Ecotoxicol. Environ. Saf. 134, 186–195.

Global Humanitarian Forum, 2009. Climate Change—the Anatomy of a Silent Crisis: Case Study: Bangladesh a Nation at the Frontline of the Climate Change Crisis, Human Impact Report Climate Change Global Humanitarian Forum Geneva. . http://www.ghf-ge.org/human-impact-report.pdf, Accessed date: 7 October 2018.

Helena, B., Pardo, R., Vega, M., Barrado, E., Fernández, J.M., Fernandez, L., 2000. Temporal evolution of groundwater composition in an alluvial aquifer (Pisuerga river, Spain) by principal component analysis. Water Res. 34, 807–816.

Hinkel, J., 2011. Indicators of vulnerability and adaptive capacity: towards a clarification of the science-policy interface. Glob. Environ. Change 21, 198–208.

Ibarraran, M.E., Ruth, M., Ahmad, S., London, M., 2009. Climate change and natural disasters: macroeconomic performance and distributional impacts. Environ. Dev. Sustain. 11, 549–569.

IPCC [Intergovernmental Panel on Climate Change], 2012. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York, USA.

Ito, S., 2002. From rice to prawns: economic transformation and agrarian structure in rural Bangladesh. J. Peasant Stud. 29, 47–70.

Karim, Z., Hussain, S.G., Ahmed, M., 1990. Salinity Problems and Crop Intensification in the Coastal Regions of Bangladesh. Soils Publication No. 33, Soils and Irrigation Division, BARC, Farmgate, Dhaka 1215, Bangladesh. pp. 1–20.

Karsili, C., Muhit, B., Hoque, M.E., Islam, S., 2013. In: Sea-level Extremes and Change-Example of Bangladesh, International Conference on Mechanical, Industrial and Materials Engineering 2013 (ICMIME2013) 1-3 November, 2013. RUET, Rajshahi, Bangladesh, pp. 772–777 Paper ID: RT-03.

Liu, C.W., Lin, K.H., Kuo, Y.M., 2003. Application of factor analysis in the assessment of groundwater quality in a Blackfoot disease area in Taiwan. Sci. Total Environ. 313 (1–3), 77–89.

McKenna Jr., J.E., 2003. An enhanced cluster analysis program with bootstrap significance testing for ecological community analysis. Environ. Model. Softw. 18 (3), 205–220.

Miyan, M.A., 2009. Monsoon in Bangladesh; Changes and Adaptation: Asian Monsoon Years AMY-6, 30 November–1 December, 2009. Kunming China.

Nakashima, D.J., McLean, G.K., Thulstrup, H.D., Castillo, R.A., Rubis, J.T., 2012. Weathering Uncertainty: Traditional Knowledge for Climate Change Assessment and Adaptation. UNESCO and Darwin: United Nations University, Australia: Paris.

Neiland, A.E., Soley, N., Varley, J.B., Whitmarsh, D.J., 2001. Shrimp aquaculture: economic perspectives for policy development. Mar. Pol. 25, 265–279.

Niles, M.T., Mueller, N.D., 2016. Farmer perceptions of climate change: associations with observed temperature and precipitation trends, irrigation, and climate beliefs. Glob. Environ. Change 39, 133–142.

O'Brien, G., O'Keefe, P., Rose, J., Wisner, B., 2006. Climate change and disaster management. Disasters 30 (1), 64–80.

Otto, M., 1998. Multivariate methods. In: Kellner, R., Mermet, J.M., Otto, M., Widmer, H.M. (Eds.), Analytical Chemistry. WileyeVCH, Weinheim.

Paul, B.G., Vogl, C.R., 2011. Impacts of shrimp farming in Bangladesh: challenges and alternatives. Ocean Coast. Manag. 54, 201–211.

Paul, S.K., Routray, J.K., 2010. Household response to cyclone and induced surge in coastal Bangladesh: coping strategies and explanatory variables. Nat. Hazards 57, 477–499.

Pender, J.S., 2008. What Is Climate Change? and How it Will Effect Bangladesh. Briefing Paper (Final Draft). Dhaka, Bangladesh: Church of Bangladesh Social Development Programme. https://www.kirkensnodhjelp.no/Documents/Kirkens%20N%C3%B8dhjelp/Publikasjoner/Temahefter/FINAL%20Draft%20WHAT%20IS%20CLIMATE%20CHANGE%20AND%20HOW%20IT%20MAY%20AFFECT%20BANGLADESH.pdf, Accessed date: 23 July 2018.

Pokrant, R.J., Bhuiyan, S., 2001. The coastal shrimp sector in Bangladesh: review of the literature with annotated bibliography. In: Ahmed, S.A., Mallick, D.L., Ali, M.L., Rahman, A.A. (Eds.), Literature Review on Bangladesh Shrimp. Individual Partner Report for the Project: Policy Research for Sustainable Shrimp Farming in Asia (PORESSFA), a Comparative Analysis of Bangladesh, India, Thailand and Vietnam with Particular Reference to Institutional and Socio-economic Aspects. European Commission INCO-DEV Project PORESSFA No. IC4-2001-10042. CEMARE University of Portsmouth UK and BCAS, Dhaka, Bangladesh, pp. 31 (2002).

Primavera, J.H., 1997. Socio-economic impacts of shrimp culture. Aquacult. Res. 28, 815–827.

Primavera, J.H., 2006. Overcoming the impacts of aquaculture on the coastal zone. Ocean Coast. Manag. 49, 531–545.

Rahman, M.A., 2010. In: Coastal Zone Management of Bangladesh Presented in the International Geosphere-biosphere Programme Synthesis Integration and Exploration: Global Environmental Change and Sustainable Development; Needs of Least Developed Countries (IGBP-LDCs) Synthesis Workshop, Maputo Mozambique September, 20–22, 2010, . feppcar.org/122/coastal-zone-management-in-bangladesh, Accessed date: 25 July 2018.

Rahman, M.A., Rahman, S., 2015. Natural and traditional defense mechanisms to reduce climate risks in coastal zones of Bangladesh. Weather Clim. Extremes 7, 84–95.

Rahman, M.M., Giedraitis, V.R., Lieberman, L.S., Akhtar, M.T., Taminskienė, V., 2013. Shrimp cultivation with water salinity in Bangladesh: the implications of an ecological model. Univers. J. Public Health 1 (3), 131–142.

Rahman, M.T.U., Rasheduzzaman, M., Habib, M.A., Ahmed, A., Tareq, S.M., Muniruzzaman, S.M., 2017. Assessment of fresh water security in coastal Bangladesh: an insight from salinity, community perception and adaptation. Ocean Coast. Manag. 137, 68–81.

Rakib, M.A., Islam, S., Nikolaos, I., Bodrud-Doza, M., Bhuiyan, M.A.H., 2017. Flood vulnerability, local perception and gender role judgment using multivariate analysis: a problem-based “participatory action to Future Skill Management” to cope with flood impacts. Weather Clim. Extremes 18, 29–43.

Seal, L., Baten, M.A., 2012. Salinity Intrusion in Interior Coast: a New Challenge to Agriculture in South Central Part of Bangladesh. http://www.unnayan.org/reports/climate/Salinity_Intrusion_in_Interior%20Coast-A_New_Challenge_to_Agriculture_in_South_Central_part_of_Bangladesh.pdf, Accessed date: 10 July 2018.

Shameem, M.I.M., Momtaz, S., Rauscher, R., 2014. Vulnerability of rural livelihoods to multiple stressors: a case study from the southwest coastal region of Bangladesh. Ocean Coast. Manag. 102, 79–87.

Shindaini, A.J.M., Baqui, G.A., 2012. Impact of shrimp cultivation on social life in rural Bangladesh: a case of Bujbunia village in Khulna district. ASA Univ. Rev. 6 (20), 129–144.

Shrestha, S., Kazama, F., 2007. Assessment of surface water quality using multivariate statistical techniques: a case study of the Fuji river basin, Japan. Environ. Model. Softw. 22, 464–475.

Sikder, M.A.I., 2013. Climate change and Bangladesh agriculture: country profile. In: Workshop on Developing Farming Systems for Climate Change Mitigation, 26–30 August 2013, Colombo.

Somani, L.L., 1991. Crop Production with Saline Water. Agro Botanical Publishers (India), IVE-176. J.N. Vyas Nagar, Bikaner 334001, New Delhi, India.

Sultana, Z., Mallick, B., 2015. Adaptation strategies after cyclone in southwest coastal Bangladesh – pro poor policy choices. Am. J. Rural Dev. 3 (2), 24–33.
Talukder, M.R.R., Rutherford, S., Phung, D., Islam, M.Z., Chu, C., 2016. The effect of drinking water salinity on blood pressure in young adults of coastal Bangladesh. Environ. Pollut. 214, 248–254.
Thomalla, F., Downing, T., Spanger-Siegfried, E., Han, G., Rockstrom, J., 2006. Reducing hazard vulnerability: towards a common approach between disaster risk reduction and climate adaptation. Disasters 30 (1), 39–48.
UNDP [United Nations Development Programme], 2018. Enhancing Adaptive Capacities of Coastal Communities, Especially Women, to Cope with Climate Change Induced Salinity. Funding proposal: 069. Green Climate Fund (GCF).
UNISDR [United Nations International Strategy for Disaster Reduction Secretariat], 2008. Briefing Note 01: Climate Change and Disaster Risk Reduction. International Environment, Geneva.
Wang, J., Liu, G., Liu, H., Lam, P.K.S., 2017. Multivariate statistical evaluation of dissolved trace elements and a water quality assessment in the middle reaches of Huaihe River, Anhui, China. Sci. Total Environ. 583, 421–431.
Wong, C.M., Williams, C.E., Pittock, J., Collier, U., Schelle, P., 2007. World's Top 10 Rivers at Risk. WWF International. Gland, Switzerland.